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Late-Glacial/Early Holocene Lake Level, Glacial Histories in the Atacama Altiplano and Potential Climate Mechanisms

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The Atacama Altiplano of the Central Andes in northern Chile (18°S - 28°S) is a key site for the study of climate change in South America. This area is currently located in the extremely arid buffer zone between the tropical summer- and the extratropical winter precipitation regime. Sediments from endorheic lakes and glacial deposits on the high elevation (above 4000 m) extremely arid (< 200 mmP yr^{-1}) Altiplano of northern Chile and NW Argentina provide information about rapid and high amplitude climate change since the last 22,000 ^{14}C yr BP [e.g., 1-4].

Initial shallow pre-LGM freshwater lakes disappeared during the extremely dry LGM conditions around 18,000 ^{14}C yr B.P. Following our ^{14}C reservoir corrected lake level chronology [5], the late-glacial paleolake transgression started around 12,000 ^{14}C yr B.P. and peaked in two phases between ca. 11,000 and <9000 ^{14}C yr B.P. interrupted by a dry interval. The paleolake transgression terminated around 8000 ^{14}C yr B.P. when shallow hypersaline lacustrine conditions and extremely arid climates were established. Energy and water balance studies of late-glacial/early Holocene paleolakes [6] suggest that annual precipitation at 23°S increased more than three times (total of > 600 mm) compared to modern conditions (~ 200 mm precipitation) which is, compared with results from climate-glacier models in the same area (1200 –10/+30 mm) [7], a rather conservative estimation.

Information about the seasonality of precipitation is hard to find in lake sediments. Long-distance transported pollen suggest partial air flow from the eastern Andes, thus tropical summer precipitation (Invierno Boliviano) and mainly similar synoptic patterns as observed today. Empirical-statistical glacier-climate models yield conclusive results regarding seasonality [7], showing that the observed glacier geometry in case study areas between 18-23°S required a summer-moist and winter-dry, moderately cold climate ($\Delta T = -3.2°C$ at 22°S), whereby contributions from winter precipitation (4 month June to September) must not have exceeded 15% of the total annual precipitation. Additional unambiguous evidence for increased tropical summer precipitation in northern Chile was found in the spatial pattern of late-glacial/early Holocene paleolakes and glacial deposits (only manifested NE of 25°S, missing between 25°S and 26°S [7]), and summer-flowering grasses in fossil rodent middens at 22-24°S [8]. It follows that an equatorward displacement of the westerlies must be discarded as a possible explanation for the late-glacial/early Holocene humid phase in the Chilean Andes north of 25°S.

Interestingly, strengthened late-glacial tropical summer precipitation coincides with a summer insolation minimum in this area. Thus in-situ Milankovitch forcing is not a suitable explanation for increased summer rainfall. However, late Quaternary humidity changes resulted in substantial modifications of the land surface characteristics in the Altiplano of the central Andes [9]. Based on a detailed field survey in a case study area (80 km x 80 km), GIS and ground-calibrated LANDSAT-TM imagery, reconstruction of surface albedo, top-of-atmosphere (TOA) albedo, and short-wave net radiation for time-windows at 20, 14, 10, 7 and 0 cal ka suggest that surface and TOA albedo increased substantially during periods of relatively humid environmental conditions (i.e., the effect of large palaeolakes was overcompensated by growing glaciers). This resulted in an overall decrease of summer short-wave net radiation and seasonality during the late-glacial/early Holocene humid phase. Thus, given that the proxy data clearly suggest summer- and not winter rainfall, in-situ radiative forcing is, in contrast to the northern hemisphere tropics, not a suitable explanation for enhanced precipitation and humid climatic conditions at that time. Our results suggest that latest Pleistocene, Holocene humidity changes on the Altiplano reflect a collective response to environmental and climate changes in the source area of the moisture (i.e., tropical-subtropical continental South America). Our ^{14}C reservoir corrected chronology for the paleolakes in the southern Altiplano is synchronous with increased humidity in the eastern Andes [10] or in the rain-forest of Central Brazil and Amazonia [e.g.,11]. Thus we consider re-expansion of the rain forest and increased release of latent heat over Amazonia and the Chaco, recycling of water vapor and transport of air masses over the continent, and thus large-scale circulation patterns (maybe even with inter-hemispherical teleconnections) as possible explanations.

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